Highly Accelerated IDEAL for Volumetric Abdominal Imaging with Fat-Water Separation in a Single Breath-hold

A. Shankaranarayanan[1], D. Sodickson[2], R. Giaquinto[3], A. Grant[2], A. Carrillo[4], D. Gurr[5], A. Madhuranthakam[6], H. Yu[1], A. Shimakawa[1], S. Joshi[5], C. Dumoulin[3], S. Reeder[7], T. Steger[5], A. Brau[1], N. Farrar[2], N. Rofsky[2], S. LaRuche[2], J. Brittain[8], C. McKenzie[2]

[1]Global Applied Science Lab, GE Healthcare, Menlo Park, CA, United States, [2]Radiology, Beth Israel Deconess Medical Center, Boston, MA, United States, [3]GE Global Research, Niskayuna, NY, United States, [4]Global Applied Science Lab, GE Healthcare, Evanston, IL, United States, [5]Engineering, GE Healthcare, Milwaukee, WI, United States, [6]Global Applied Science Lab, GE Healthcare, Boston, MA, United States, [7]Radiology, Madison, WI, United States, [8]Global Applied Science Lab, GE Healthcare, Madison, WI, United States

Introduction:

Contrast-enhanced imaging of the abdomen requires robust fat suppression, complete volumetric liver coverage, and short scan times to ensure patient breath-hold compliance. IDEAL (Iterative Decomposition of water-fat with Echo Asymmetry and Least-squares estimation) is a chemical-shift based fat-water separation method that offers improved water-fat separation compared to conventional fat suppression techniques [1,2]. The three-point IDEAL method is SNR efficient, with resulting water and fat images having a Number of Signal Averages (NSA) of three. However, the three-fold scan time increase compared to a non-fat-suppressed acquisition has limited the clinical use of IDEAL in time-sensitive applications such as breath-held abdominal imaging and contrast-enhanced studies. Previous work has combined IDEAL with parallel imaging methods [3]. Although IDEAL provided improved fat-water separation, the moderate acceleration factors utilized were insufficient to achieve coverage and resolution comparable to current clinical protocols.

In this work, we demonstrate IDEAL with a self-calibrated, highly accelerated acquisition on a 32-channel system. This combination enables the extension of the robust IDEAL fat-water separation technique into the previously unattainable clinical realm of contrast-enhanced, high-resolution breath-held abdominal imaging.

Methods:

Data were acquired on a 32 channel TwinSpeed system (GE Healthcare Technologies, Waukesha, WI) [4] using a symmetric body-optimized 32-element two-dimensional, underlapped array consisting of two clamshell formers equipped with 16 anterior elements and 16 posterior elements (Fig 1) [5]. A 3D gradient echo sequence was modified to acquire three echoes with echo times selected to achieve an NSA of approximately three [6]. A variable-density self-calibrating scheme [7] was used, with sensitivity maps generated from 24x24 fully sampled central points and with the remaining points undersampled in the Y-Z plane. In the initial experiments, variable k-space density was applied to all three echoes and the self-calibrated first echo was used for obtaining sensitivity maps. However, in general, the extra lines of k-space could be acquired as part of only one of the three echoes, allowing still higher accelerations, or else an external calibration strategy could be used, at the expense of an increased risk of motion/miscalibration artifacts. The 3D sequence used the following imaging parameters: 320x160x60 data matrix (after reconstruction), FOV = 38cm, flip = 12^o, receiver BW = $\pm$83kHz, TE1 = 1.9ms, TE2 = 3.6ms, TE3 = 5.2ms and TR = 6.4ms. In some cases, the z-encoding direction was sampled partially and was reconstructed using zero-filling. An acceleration factor of 2 was applied in the phase direction and an acceleration factor of 4 was applied in the slice direction, in addition to the partial z encoding. The Generalized Encoding Matrix (GEM) approach [8] was used to reconstruct the accelerated (Y-Z) planes. The GEM reconstruction was performed on 14 processors in parallel to reduce reconstruction time. GEM-reconstructed slices were then passed through the standard 3-point IDEAL processing algorithm [1] to obtain water, fat, in-phase and out-of-phase images.

Following informed consent, contrast-enhanced studies with the highly accelerated IDEAL technique were performed on volunteers. The institution's standard clinical protocol was used. The scan time was limited to breath-holds (25-30s) and the slab was optimized to provide complete liver coverage (24-32cm). Acceleration factors were then optimized to meet breathhold scan time constraints. Typically, one pre-contrast 3D data set and three post-contrast data sets corresponding to arterial, venous, and late phase were obtained. The images were qualitatively observed for g-factor induced noise.

Results:

Figure 2 shows three slices of the pre-contrast abdominal water (a) and fat (b) images from a volunteer. Parallel imaging acceleration of 4.5 (accounting for the fully-sampled central k-space lines) and net acceleration of 6.4 (including partial z-encoding) was achieved in this study. No pronounced g-factor-related noise amplification was seen, even at the high acceleration factors used for the outer portions of k-space. Such acceleration factors allowed large z-coverage (24cm) while giving an in-plane resolution of 1mm x 2mm and typical scan times of 25-28s. Also note the uniform separation of fat and water. Figure 3 shows the post contrast (venous phase) water and fat images. Again, uniform fat-water separation is observed.

Discussion and Conclusion:

The ability to achieve high acceleration factors with many-element arrays enables the use of a robust and SNR-efficient but time-consuming fat-water separation technique like IDEAL while respecting the relatively stringent time constraints of clinical breath-held scanning. The absence of g-factor noise and the good SNR demonstrated in these images indicate that even higher acceleration factors may be possible, enabling higher spatial resolution or larger coverage. Highly accelerated IDEAL imaging is a promising method for volumetric abdominal imaging.

References:

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Figure 1: Sixteen elements of the 32-element array. Only the anterior portion of the array is shown.

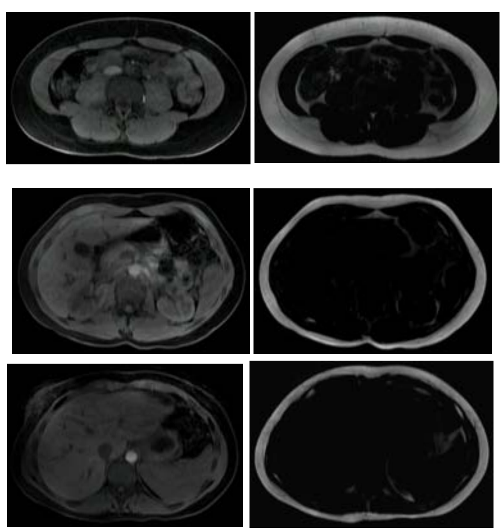

Figure 2: Pre contrast (a) water and (b) fat images from various locations. Note the absence of visible g-factor noise even with the high acceleration factors.

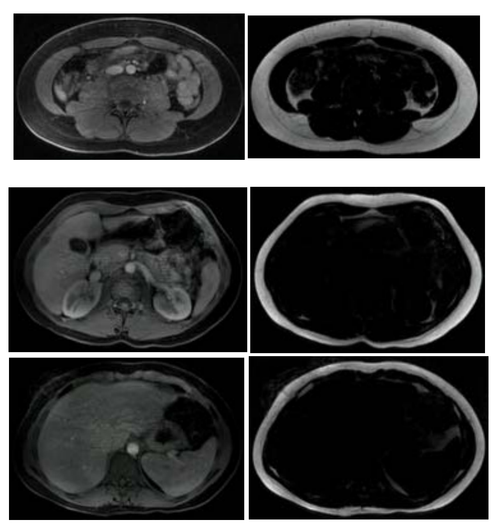

Figure 3: Post contrast (a) water and (b) fat images from the same locations shown in Figure 2. Note the uniform fat-water separation. A coverage of ~24cm was achieved.